Steps Toward the Big Detector

- The Ultimate Step
- The Penultimate Step

- Costs and NuSAG

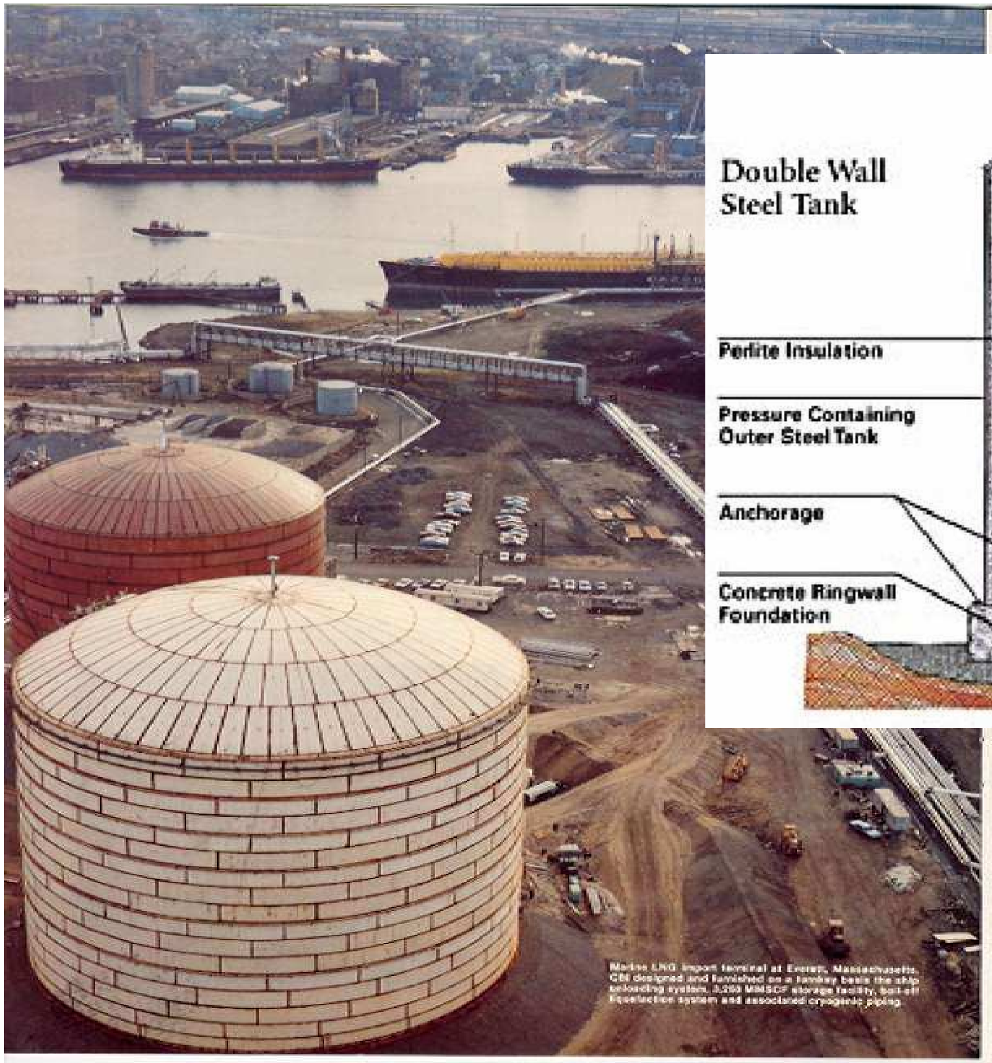
- Some On-Going R&D Steps at Fermilab

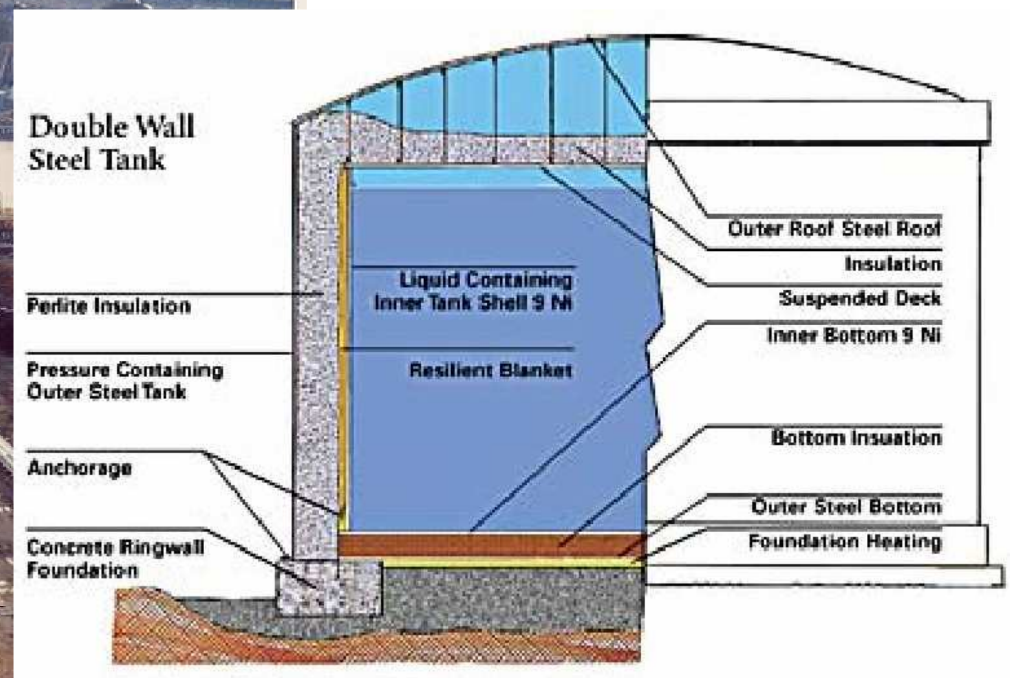
The Ultimate Neutrino Detector

Adam Para, Fermilab

Experimental Seminar,
SLAC,
March 28, 2006

Detector Tank based on Industrial Liquefied Natural Gas (LNG) storage tanks



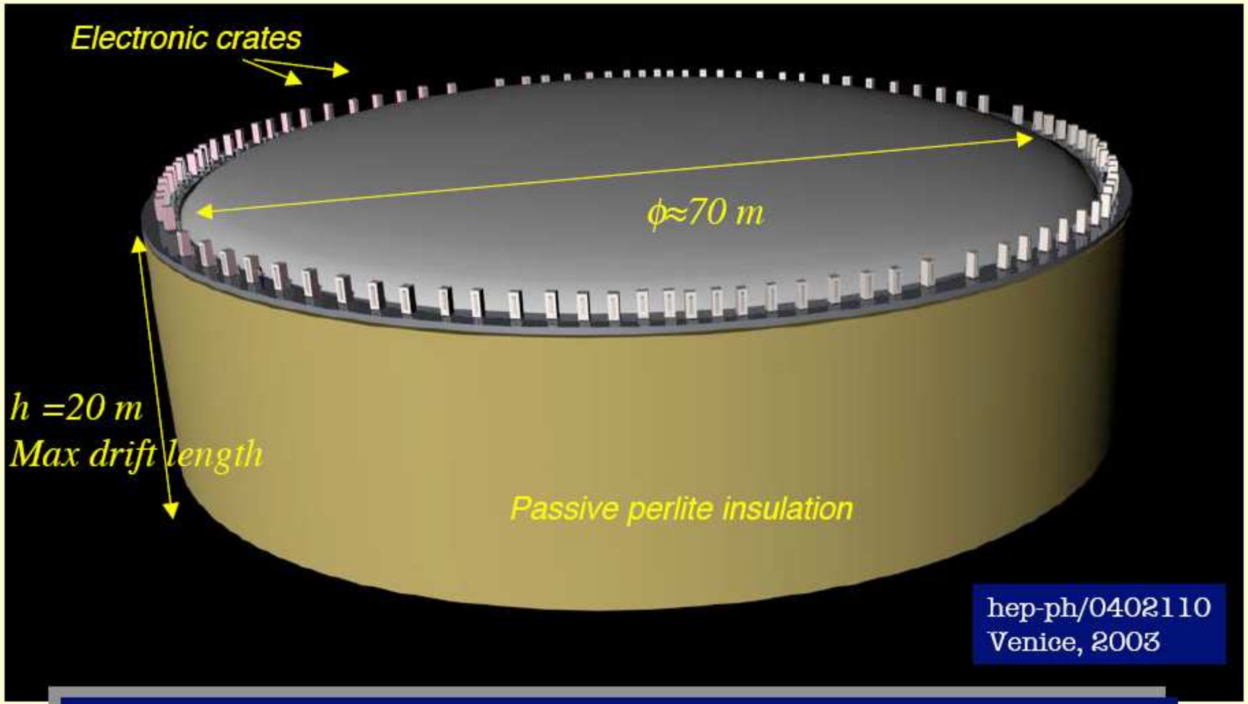


Many large LNG tanks in service. excellent safety record

André Rubbia (ETH Zürich)

http://neutrino.ethz.ch/GLACIER/

A 100 kton liquid Argon TPC detector



Single module cryo-tanker based on industrial LNG technology

A "general-purpose" detector for superbeams, beta-beams and neutrino factories with broad non-accelerator physics program (SN ν, p-decay, atm ν, …)

International Neutrino Factory And Superbeam Scoping Study Meeting, CERN - 22-24 September 2005

The Big Question:

What is needed to take the Ultimate Step for Large Liquid Argon TPC Detectors?

This begs a smaller question:

What is the "Penultimate Step"?

The Ultimate Step

- Assumptions for beginning the ultimate step:
  - A timely, cutting edge physics justification
    - Examples may be:
    - Proton decay, supernovae, perhaps “finishing” neutrino oscillations, etc
  - A project with well-understood technical capabilities and costs for a 50 kton (<u>at least</u>) TPC liquid argon detector
  - An international collaboration which proposes to international funding agencies locating one or more detectors:
    - Under rock/dirt in Europe, the Americas, Asia or elsewhere
    - On the surface anywhere on the planet (including in a neutrino beam)

The Penultimate Step

- Beginning the penultimate step assumes completion of:
  - A compelling physics case for the penultimate step (and perhaps the ultimate step)
    - In the context of a globally coordinated neutrino physics program … which in turn requires
    - An international collaboration in place with possible, but likely unapproved, funding sources for the Ultimate Detector, and
  - A credible schedule, which requires (see later slides):
  - A credible cost estimate, which requires (see later slides):
  - A demonstration of the engineering/technology (ICARUS / T600 is an existence proof of one approach) and the plausibility of the experimental physics capability for the Penultimate Detector

Penultimate Detectors

- There are many examples of Penultimate Detectors, but they all have these criteria:
  - A compelling physics experiment justifies the Penultimate Detector
    - a physics justification is needed because it costs tens of millions of dollars
  - The relationship of the Penultimate Detector to determining the scalability of the technology to the Ultimate Detector, and its cost, must be clear.
  - The Penultimate Detector is part of a global neutrino physics program and almost surely requires international coordination and funding

Penultimate Detector Physics Cases

* active mass

- **3 to 4 kton* LArTPC at Soudan**
  - On the surface is ~1mrad off axis = “nearly on-axis”
  - Physics Case ??
    - theta_13, theta_23, mass hierarchy, other ? …
    - complementary to NOvA ???
- **3 to 4 kton* LArTPC at Ash River (next to NOvA).**
  - Goal for Physics Case: Increase the NOvA physics output.
  - [Note to DOE: If considerable INFN / European help and financing come true, the cost to DOE would be less than ~10% of the NOvA detector total cost.]
- **3 to 4 kton* LArTPC in Italy.**
  - Physics Case ??
  - theta_13, theta_23, mass hierarchy, other ? …
  - Note: This is five times the mass of T600.
  - What can we do with this capability?

The Penultimate Step

- Making the penultimate step requires completion of:
  - A credible schedule, which includes:
    - Time for peer reviews, lab reviews, and government approvals
    - Completion of R&D for the engineering/technology and physics capability required for the Penultimate Detector
    - Time for construction and operation of the Penultimate Detector
  - A credible cost estimate, which requires:
    - A technical design to accomplish the physics
    - A credible schedule
    - Engineers and project management techniques
    - A clear cost scaling to the Ultimate Detector

Cost History: What has been done?

- ICARUS
  - ~$20M for 1.2 kton (actually 20M Euros, and tonnes not tons)
    - Math gives: ~17M$/kton or ~830M$/50 kton
    - And math gives: a factor of ten cheaper would be ~83M$/50kton
    - This is an “experienced based” cost estimate.
    - This is not a cost done by DOE accounting.
- LArTPC NuSAG submission
  - $57.45M for 15 kton
    - Math gives: 3.8M$/kton or ~190M$/50kton
    - This is not an “experience based” cost estimate.
    - International collaboration / funding was not assumed.
    - This is not a cost done by DOE accounting.
- NuSAG response
  - See next slides

Aside: What is NuSAG?

- The US Government's Department of Energy and National Science Foundation get advice from many committees. One of them is HEPAP.
  - HEPAP (High Energy Physics Advisory Panel) advises the HEP decision makers in the DOE and the NSF.
  - P5 (Particle Physics Project Prioritization Panel) receives charges from HEPAP and responds to HEPAP.
  - NuSAG (Neutrino Science Assessment Group) gathers information for P5 on US neutrino physics needs.

NuSAG February 28, 2006

6.2.3 The U.S. R&D program in Liquid Argon TPC's should be supported at a level that can establish if the technology is scalable to the 10-30 kiloton range. If workable, this technology will come into its own in the later phases of the long-baseline program.

NuSAG's charge suggested that we consider this technology as an alternative to NOvA. This was not the case presented to NuSAG by the proponents or by Fermilab. Instead, use of a liquid argon neutrino detector in later phases of the program is contemplated, possibly for a second detector in the NOvA program.

Besides dealing with longer wires, higher voltage, and longer drift times than the existing Icarus modules, cost reduction by about an order of magnitude will be required to make a 10-30 kiloton detector feasible.

LArTPC NuSAG Submission Costs

Item (15 kton)	cost (k$)	Comment
Site Preparation	5,300	same as NOvA
Buildings	2,000	support buildings only
Tank	13,300	e-mail quote
Habitable Deck	2,500	$300/sq ft.
Tank Top Structure	4,000	Wire Load/Tank Pressure
Cathode and Field Cage	3,000	Eng. Estimate
Signal Planes	3,000	Eng. Estimate
Access to Deck	1,500	Elevator and Stairways
Assembly Platforms	1,000	Installation of TPC
Total	**35,600**	

Table 7.1: Estimate for Mechanical Infrastructure

Item (15 kton)	cost (k$)	comment
Argon	13,000	2004 quote
LAr purifiers	800	Commercial (includes spare)
Tank atmos. purification	500	eng. estimate
LAr Receiving & Transfer	1,500	3 stations
LAr Instrumentation & Controls	250	Commercial Software/Hardware
LN_2 Storage and Pumps	300	includes back-up
LN_2 Instrumentation & Controls	100	Commercial Software/Hardware
Heat Exchangers	100	eng. estimate
Total	**16,550**	

Table 7.2: Estimate for Cryogenics Material and Systems

Item (15 kton)	cost (k$)	Comment
Front-End ASIC	1,000	ASIC development & production
Commercial Components	500	ADC, FPGA and Data Link
Connectors, cable, PC Boards	1,100	Parts & similar boards
Feedthroughs	300	Purchasable Devices
Power Supplies	200	
Total	**3,100**	

Table 7.3: Estimate for Electronics

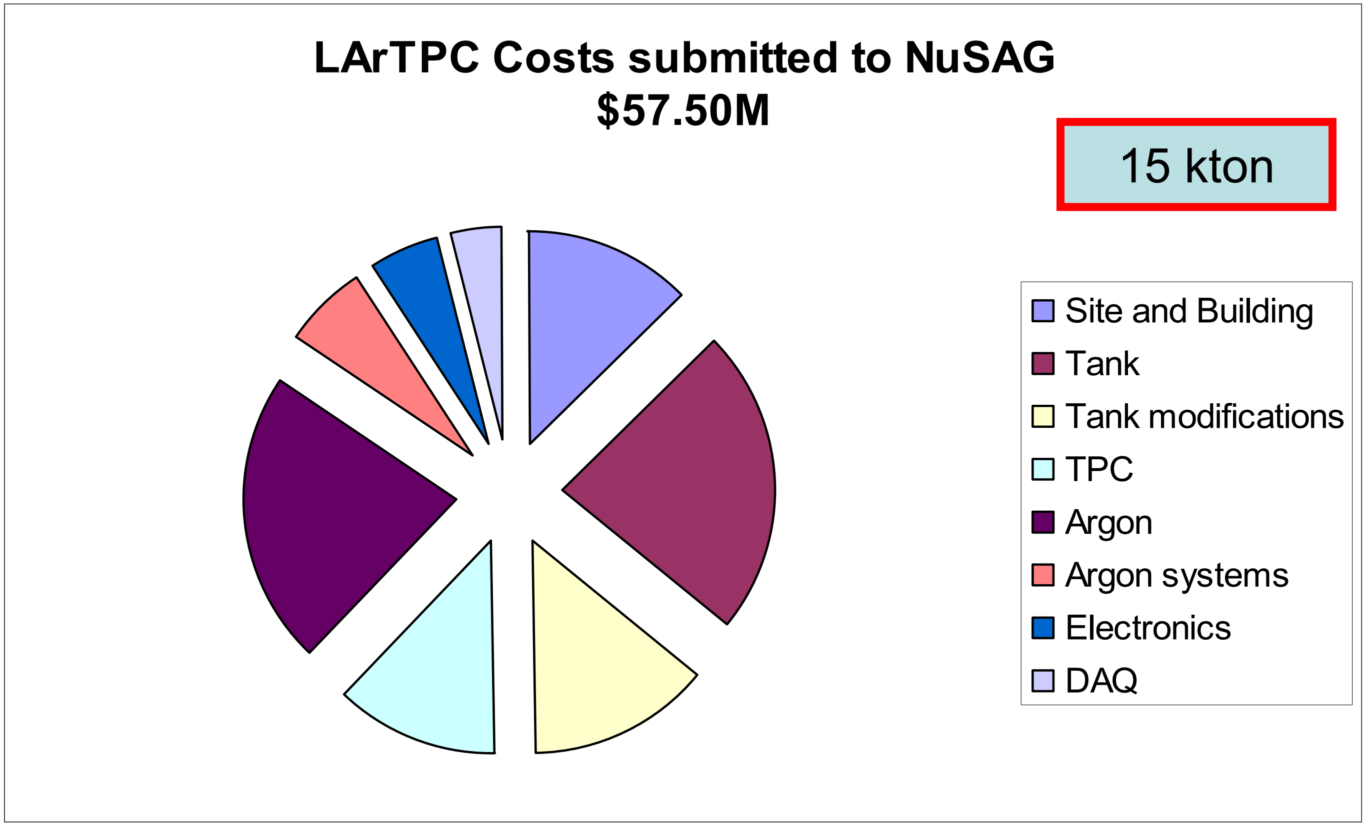
Item (15 kton)	cost (k$)	Comment
Switches & cable	50	Commercial Product
Computers	500	200 PCs
Slow Controls	200	Eng. Estimate
Timing System	100	Eng. Estimate
Data Storage	1200	2 Pbytes[1]
Development Systems	200	Eng. Estimate
Total	**2,250**	

Table 7.4: Estimate for Data Acquisition

15 kton

The costs presented in this chapter add up to a total of 57.45 Million dollars. This is a preliminary cost estimate which does not include EDIA or contingency.

NuSAG LArTPC Cost Pie



The costs presented in this chapter add up to a total of 57.45 Million dollars. This is a preliminary cost estimate which does not include EDIA or contingency.

Using cost estimates …

- Any cost estimate can be used to …
  - Identify large costs (and cost uncertainties) which might be reduced by
    - technical R&D including more detailed engineering designs or
    - getting information which is closer to firm quotes from vendors
  - Increase costs to reduce risk or improve technical performance, or to advance/stretch the schedule (for whatever reasons)
  - Help identify all tasks (i.e., costs) by using a WBS
  - Compare to other techniques and approaches (e.g. Water Cherenkov, surface vs. below ground, etc.)
  - Allow all participants (physics groups, directorates, funding agencies etc) to clearly see which pieces of the pie they are taking on.

D. Finley to DOE Annual Review of Fermilab
May 17, 2006

Fermilab efforts on LArTPC

- Focusing technical effort on issues related to the "Big Tank"
  - Finish the assembly of a Purity Test Station to qualify materials for the Big Tank
  - Model and measure how well one can use argon gas, as a first step, to purge oxygen from large tanks similar to the Big Tank
  - Understand the issues for integrating a TPC with long wires into the Big Tank (mechanical issues, electrical issues, the TPC surviving in a big bath of LAr, achieving and maintaining LAr purity with a TPC in it, etc)
- Building on FLARE LoI of August 23, 2004
- Forming people connections which should lead to collaboration(s) including people from INFN, ICARUS, universities and elsewhere

Some On-Going R&D Steps (This talk)

- Big Tank R&D
  - Purity Test Station to qualify materials for big tank
  - Achieving required argon purity without vacuum and clean room techniques
- D > H Tanks
  - Not like GLACIER, due to vertical wires
  - Allows use of shorter wires
  - Less efficient use of argon, more electronic channels needed
  - Limiting the length to ~20 meters begins to be important for mass > ~10 ktons.

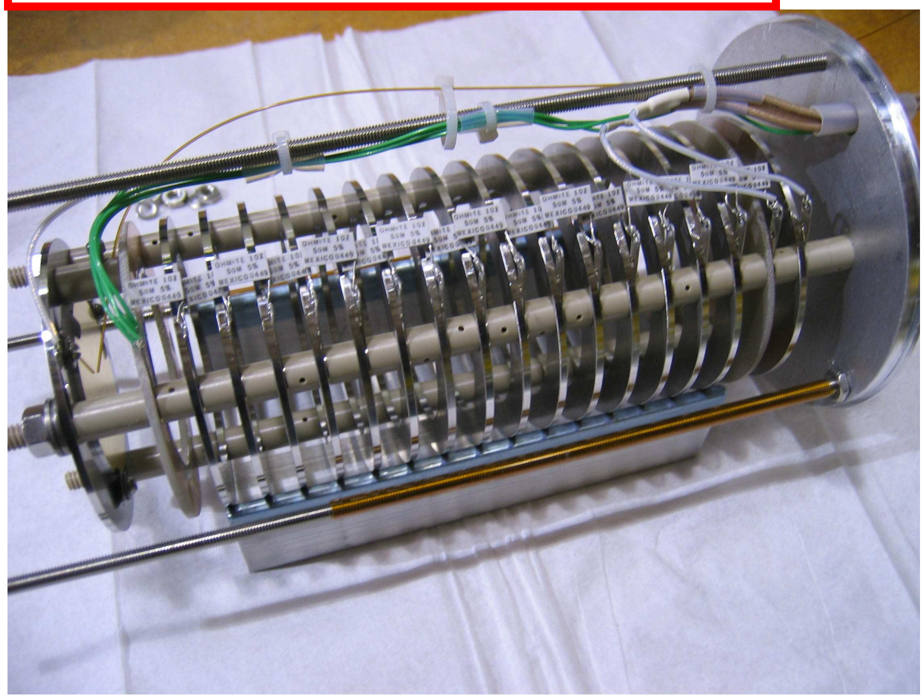
Some On-Going R&D Steps (Other talks)

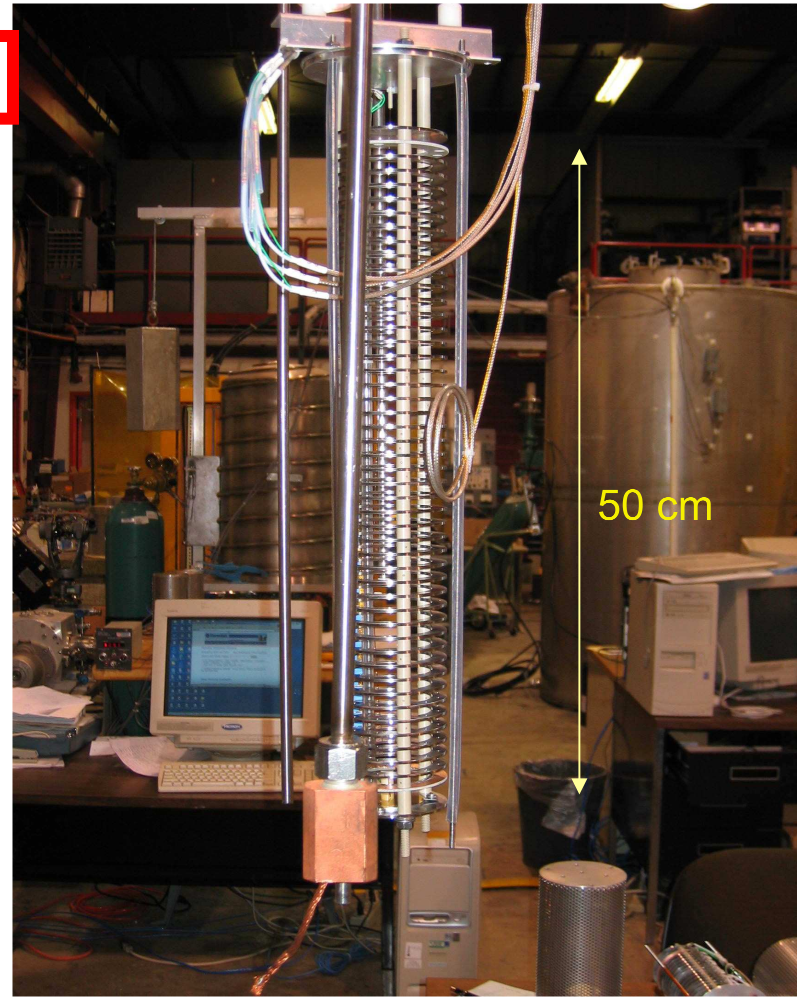
- Cellular TPC design (see Carl Bromberg's talk July 12)
  - Allows cell construction in many locations
  - Perhaps provides a shorter project schedule
- Cold electronics (see Carl Bromberg's talk July 12)
  - Allows one to use shorter wires but may cost money
- Design Against Cosmic Rays (see Stephen Pordes' talk July 12)
  - Not in Stephen's talk
    - Go underground!
    - Use plane spacing less than 3 meters, use shorter wires
  - Is this really an issue, or just a worry?
- LongBaseLine Study (see Bonnie Fleming / Regina Rameika's talk July 11)

Purity Monitors

Long Purity Monitor - for long drift life times

ICARUS Clone made at Fermilab





Purity Test Station at Fermilab
(under development)

A test station to study (a) the contamination of LAr by various materials and (b) the efficacy of various 'filters' for the removal of oxygen (and other electronegative species)

In May 2006, we achieved a purity which scales to a 3 meter drift with a 20% loss of electrons, meeting our goal for electron lifetime in the Big Detector.

Purging a “Small Tank”

- The “Village water tank” has a volume the same as ~1,000 tons of liquid argon (1.40 g/cm^3).
- It was part of the village of Weston.
- The intention is to use it to challenge models of purging tanks with a “piston” of argon gas.
- Question: How does sunshine mess up the measurement?

1 kton represents the smallest “quantum”

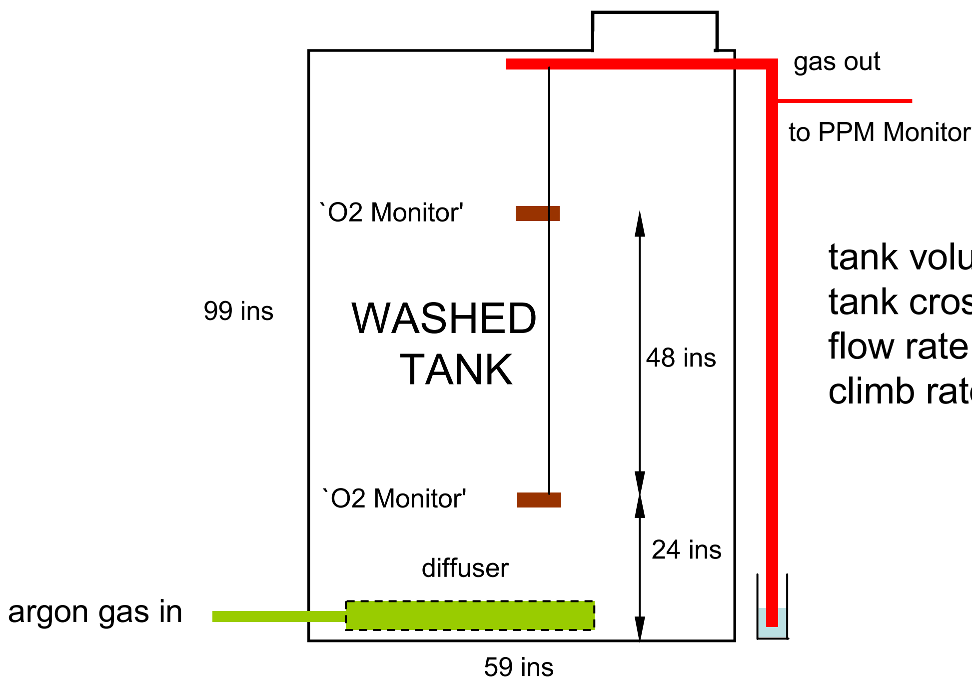
First: Purge a "Tiny Tank"

Test of purging a volume from atmosphere:

insert Argon gas at bottom of tank over large area at low velocity;

the Argon introduced being heavier than air will act as a piston and drive the air out of the tank at the top;

fewer volume changes than simple mixing model will achieve a given reduction in air concentration.

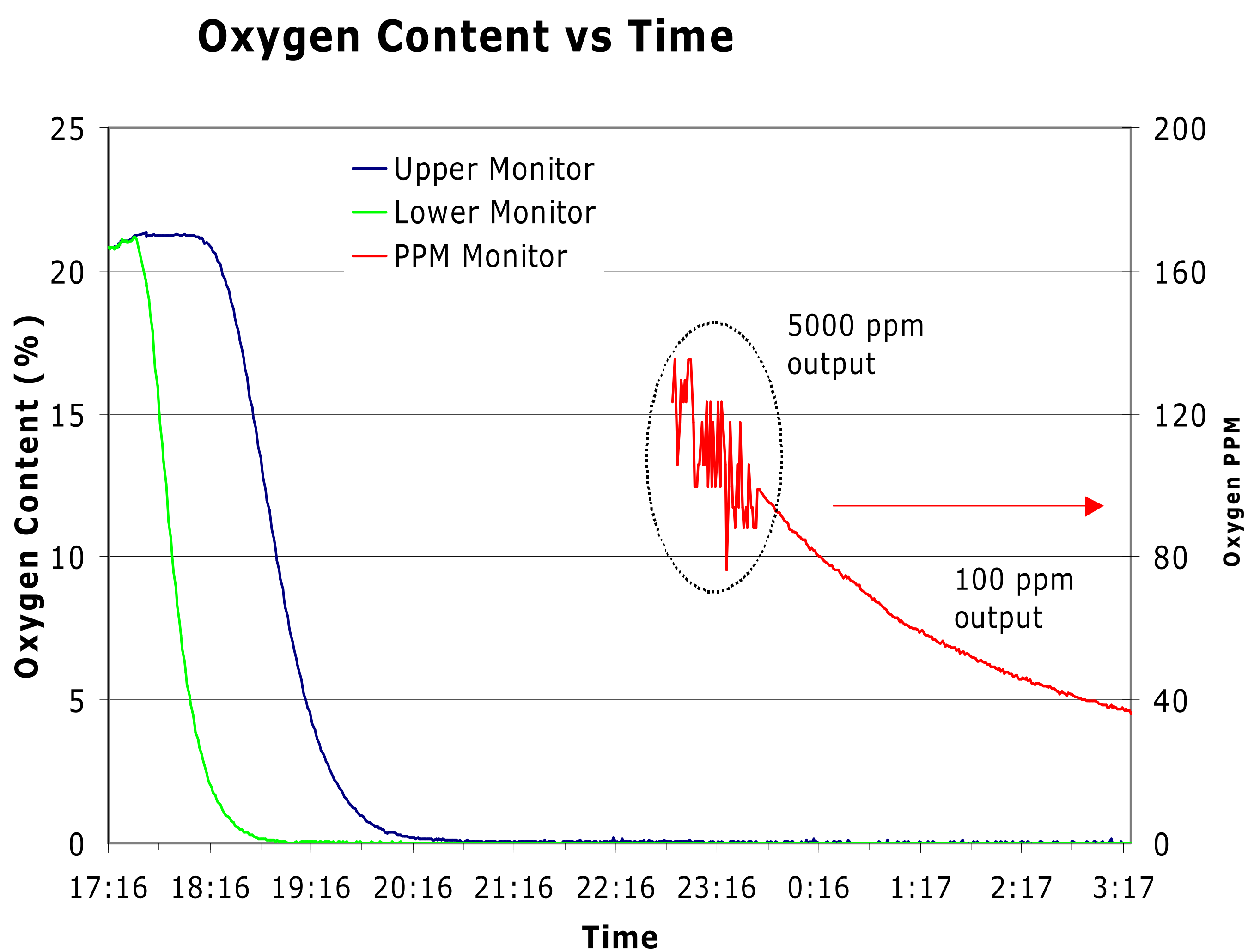


tank volume = 157 cf
tank cross section = 19 sf
flow rate ~ 73.2 cf/h (reading for air was 86 scfh)
climb rate ~ 3.8 f/h

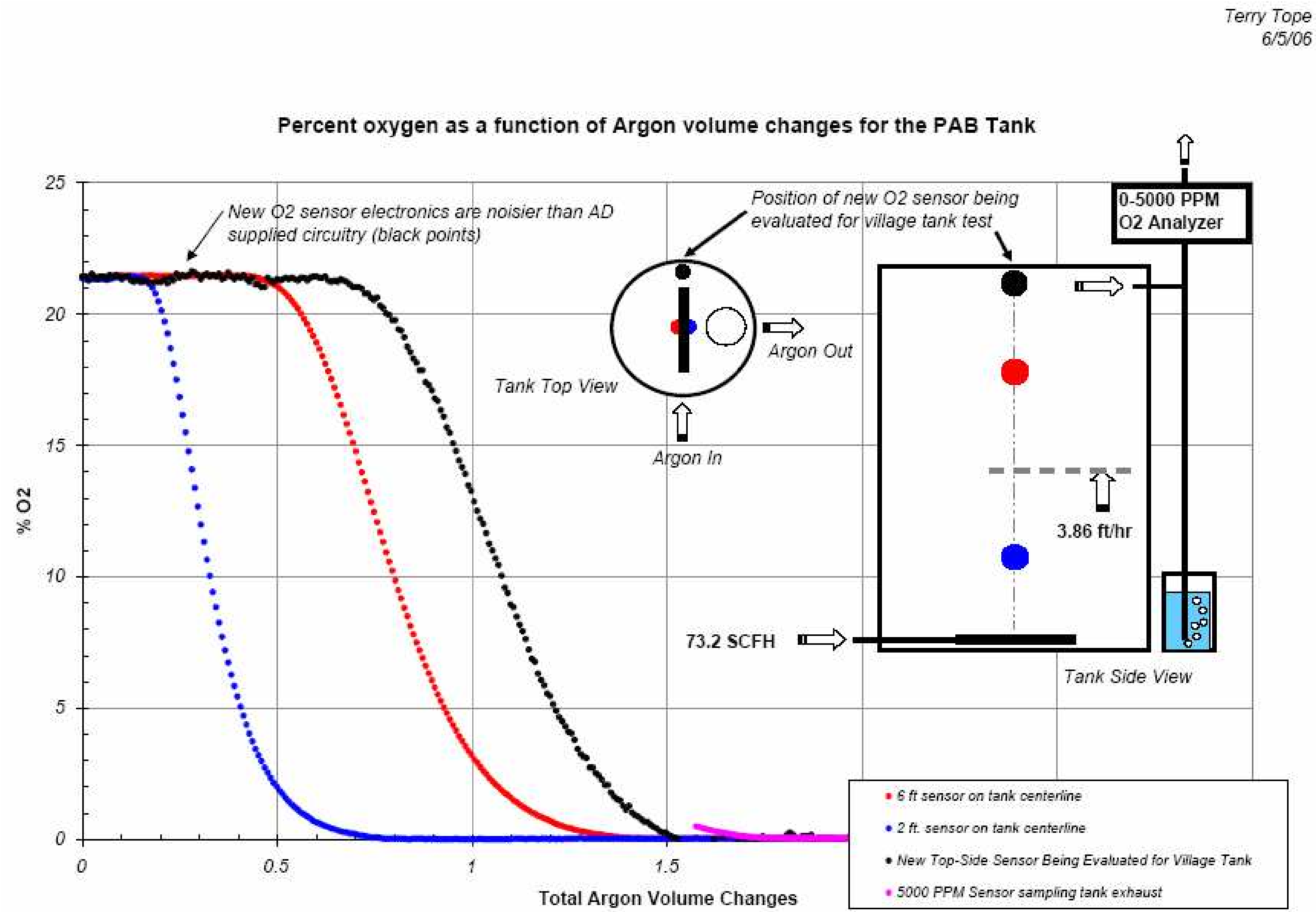
The Tiny Tank …

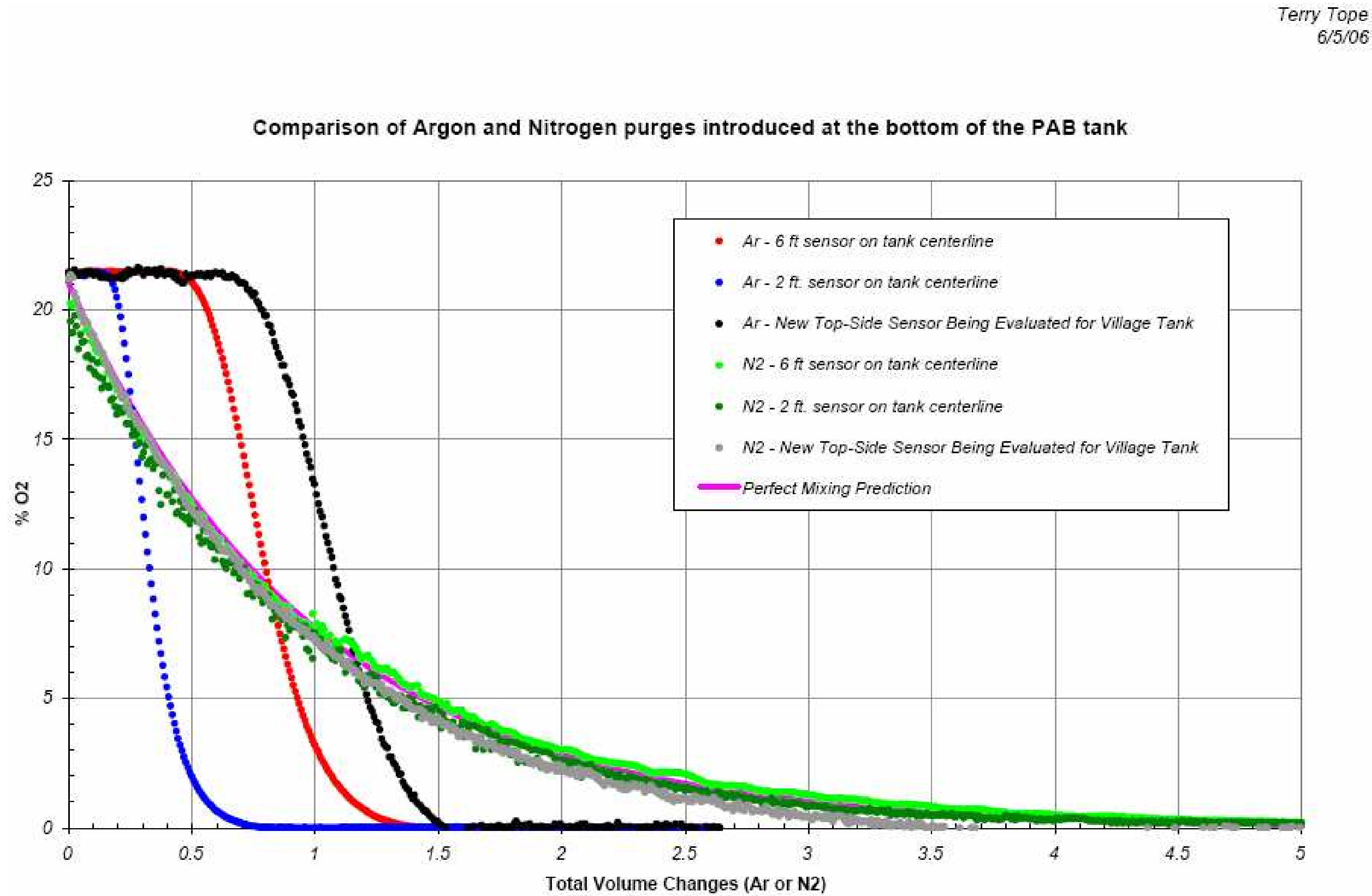
… behind an average sized Engineer.

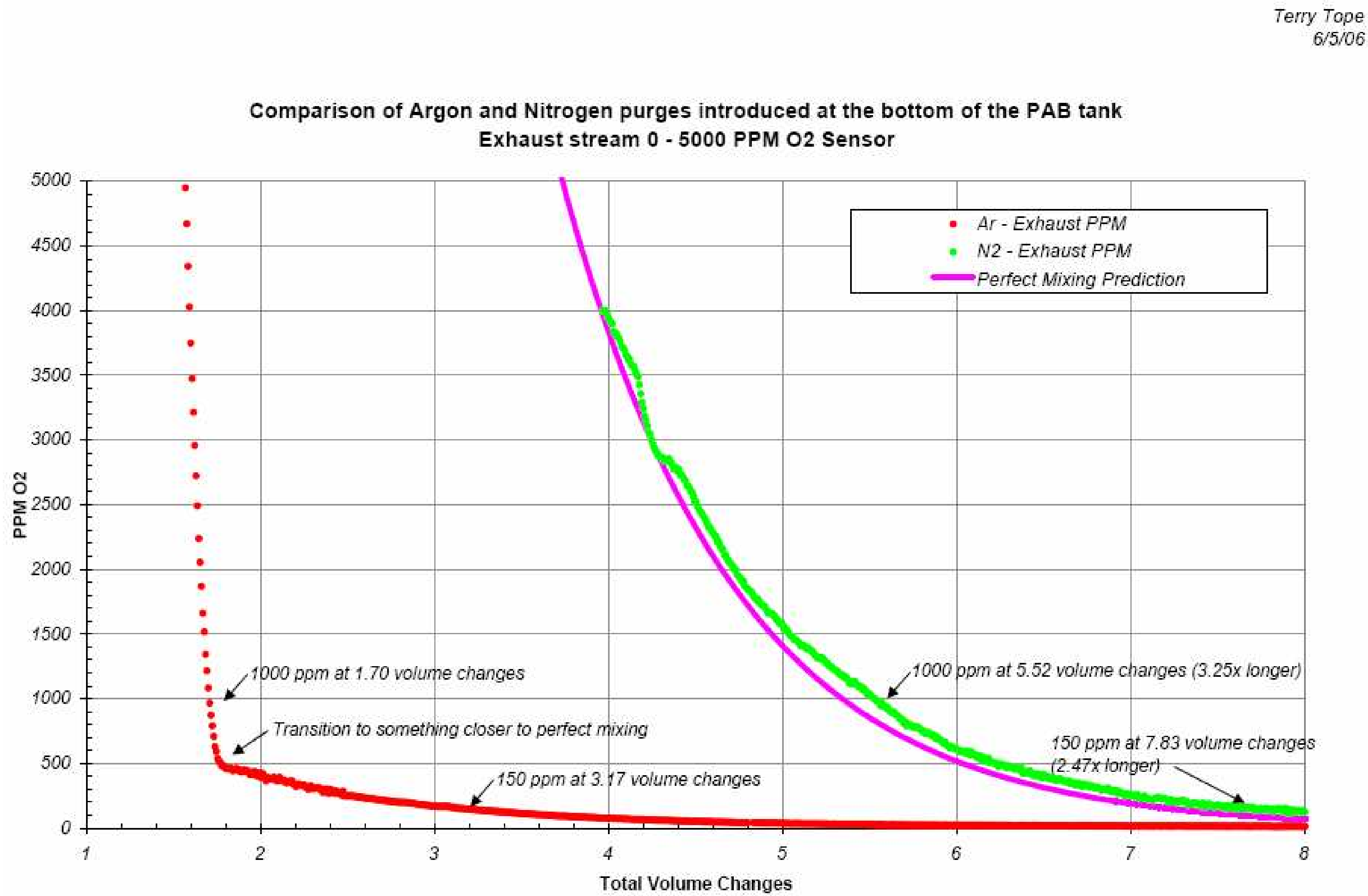
(The very small tank to his right is a “bubbler”.)



to 100 ppm (reduction of 2,000) takes 6 hrs = 2.6 volume changes
(cf simple mixing, which predicts ln(2000) = 7.6 volume changes)


Terry Tope
6/5/06
Percent oxygen as a function of Argon volume changes for the PAB Tank
25
20
15
10
5
0
% O2
0
0.5
1
1.5
Total Argon Volume Changes
New O2 sensor electronics are noisier than AD supplied circuitry (black points)
Position of new O2 sensor being evaluated for village tank test
0-5000 PPM O2 Analyzer
Argon Out
Tank Top View
Argon In
3.86 ft/hr
73.2 SCFH
Tank Side View
6 ft sensor on tank centerline
2 ft. sensor on tank centerline
New Top-Side Sensor Being Evaluated for Village Tank
5000 PPM Sensor sampling tank exhaust

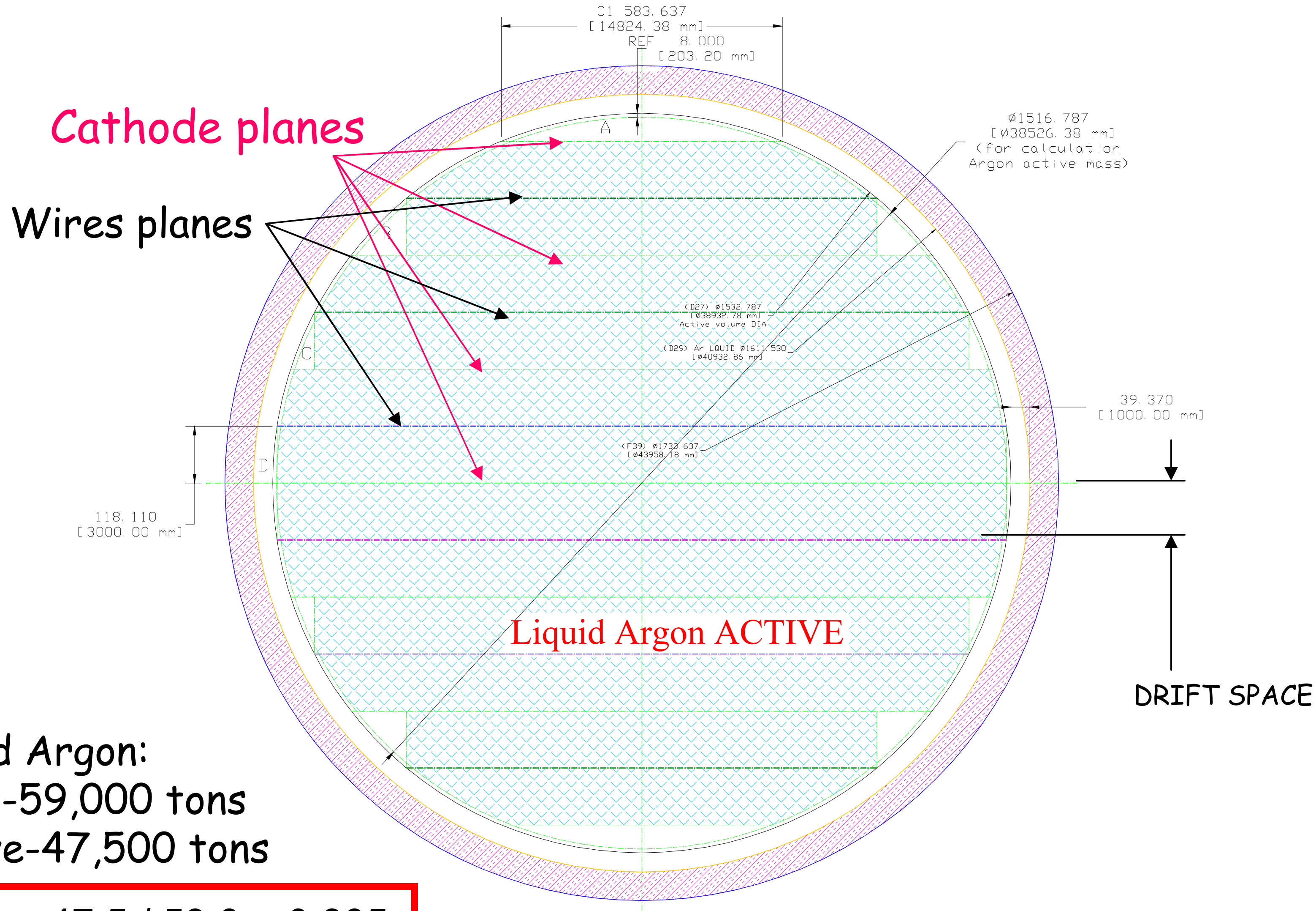

Terry Tope
6/5/06
Comparison of Argon and Nitrogen purges introduced at the bottom of the PAB tank
Ar - 6 ft sensor on tank centerline
Ar - 2 ft. sensor on tank centerline
Ar - New Top-Side Sensor Being Evaluated for Village Tank
N2 - 6 ft sensor on tank centerline
N2 - 2 ft. sensor on tank centerline
N2 - New Top-Side Sensor Being Evaluated for Village Tank
Perfect Mixing Prediction
% O2
25
20
15
10
5
0
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
Total Volume Changes (Ar or N2)


Terry Tope
6/5/06
Comparison of Argon and Nitrogen purges introduced at the bottom of the PAB tank
Exhaust stream 0 - 5000 PPM O2 Sensor
PPM O2
Total Volume Changes
Ar - Exhaust PPM
N2 - Exhaust PPM
Perfect Mixing Prediction
1000 ppm at 1.70 volume changes
Transition to something closer to perfect mixing
150 ppm at 3.17 volume changes
1000 ppm at 5.52 volume changes (3.25x longer)
150 ppm at 7.83 volume changes
(2.47x longer)
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
1
2
3
4
5
6
7
8

What about “many small” tanks?

- Is it <u>not</u> obvious that there are added costs for the “many small” approach?
- Yes … (see next slides) … but
  - How much is not used efficiently and
  - What does the increased cost buy?

LArTPC 50KT. (section B-B)

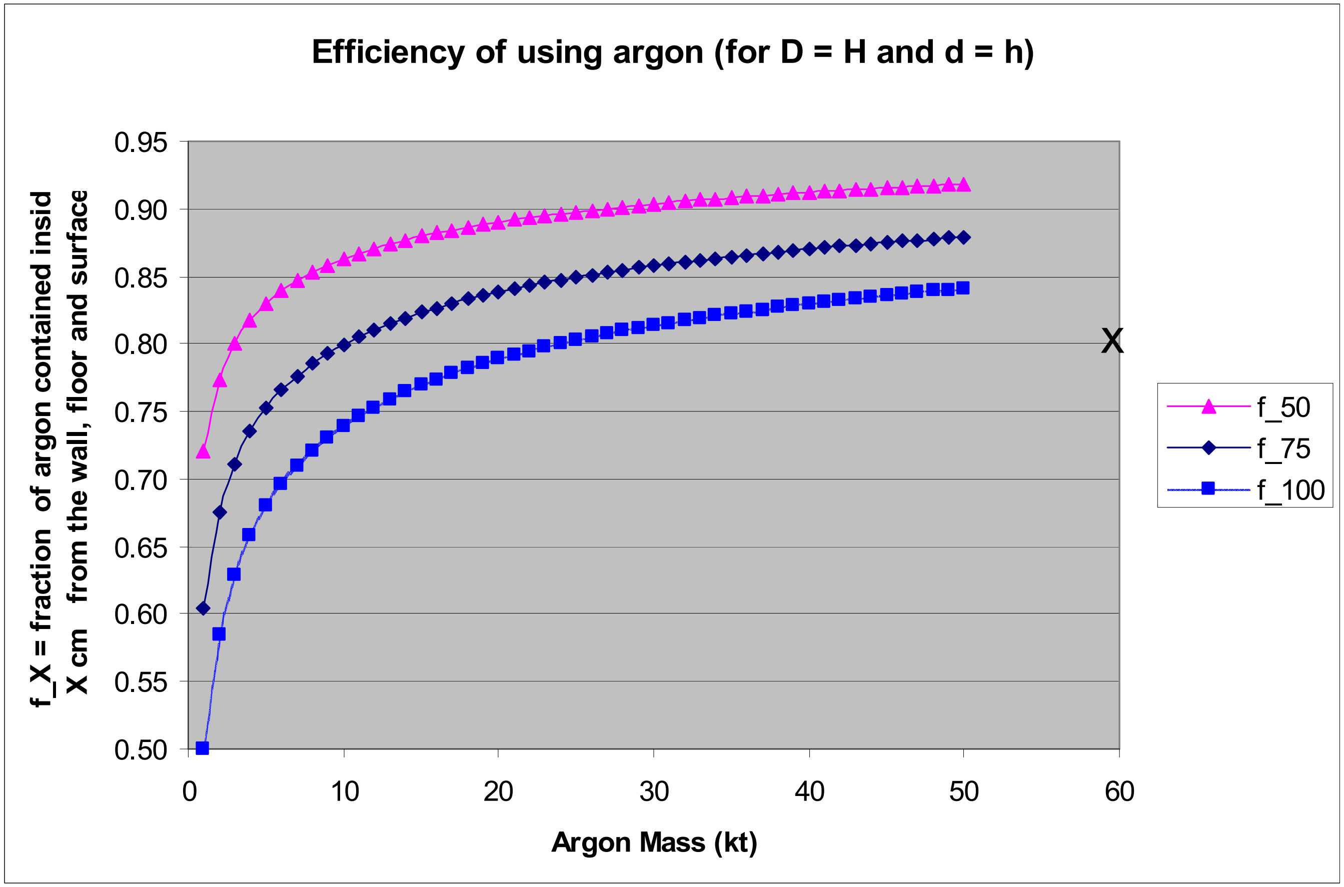


SECTION B-B

Liquid Argon:
Total-59,000 tons
Active-47,500 tons

Note: 47.5 / 59.0 = 0.805

Fraction left after removing d=h
(at the side, the top and the bottom of the argon)



Example with d=h=1m.

A single 50 kton total argon tank yields 42.1 ktons.

A single 10 kton total argon tank yields 7.39 ktons.

Thus, it would take 42.1/7.39 = 5.68 of the 10 kton tanks to yield the same as a single 50 kton tank.

$$\text{fraction} = [\ 1 - 2\ d\ /\ D\ ]^3$$

Note: X marks 47.5 / 59.0 = 0.805

Comments: “Many, Smaller” Tanks

- What does the increased cost buy?
  - Reduction in risk by having shorter wires … but how short is short enough?
  - “Obvious” control of systematics … but how well does a single large detector need to control systematics? And how does it control systematics?
  - Allows for staging of data taking … and reducing technical risks by proving / improving the capability of the prototype
  - Reduces catastrophic risks by not having all the “eggs in one basket” (i.e., the one TPC in the one Tank).

Latest Guidance from NuSAG

NuSAG Suggestions/Questions for the Long-baseline Working Group
June 27, 2006

For Liquid Argon:

13. NuSAG recommends that the Liquid Argon group reweight its emphasis from sensitivity/reconstruction/pattern recognition to hardware issues and cost estimates. We realize that a full switch cannot occur if the LAr group is a big part of the more generic off-axis calculations in the Working Group, but, for example, LAr-specific reconstruction and particle ID algorithms seem less pressing than technical feasibility.

14. What has actually been measured on purity of the Ar in a tank made with industrial technology? If not yet tried, when will the first tests be?

15. When do you expect to have tried 3-m drifts and long wires in the US? What effect will the capacitance of very long wires have on electronic noise?

16. What are the R&D milestones, with an estimated schedule, that would lead to a first realistic cost estimate for a detector of the 2nd-off-axis or wide-band class?

Liquid Argon TPC Overview for NuSAG

Note: At this point in time …

"15" could be "50"

"1" could be "3"

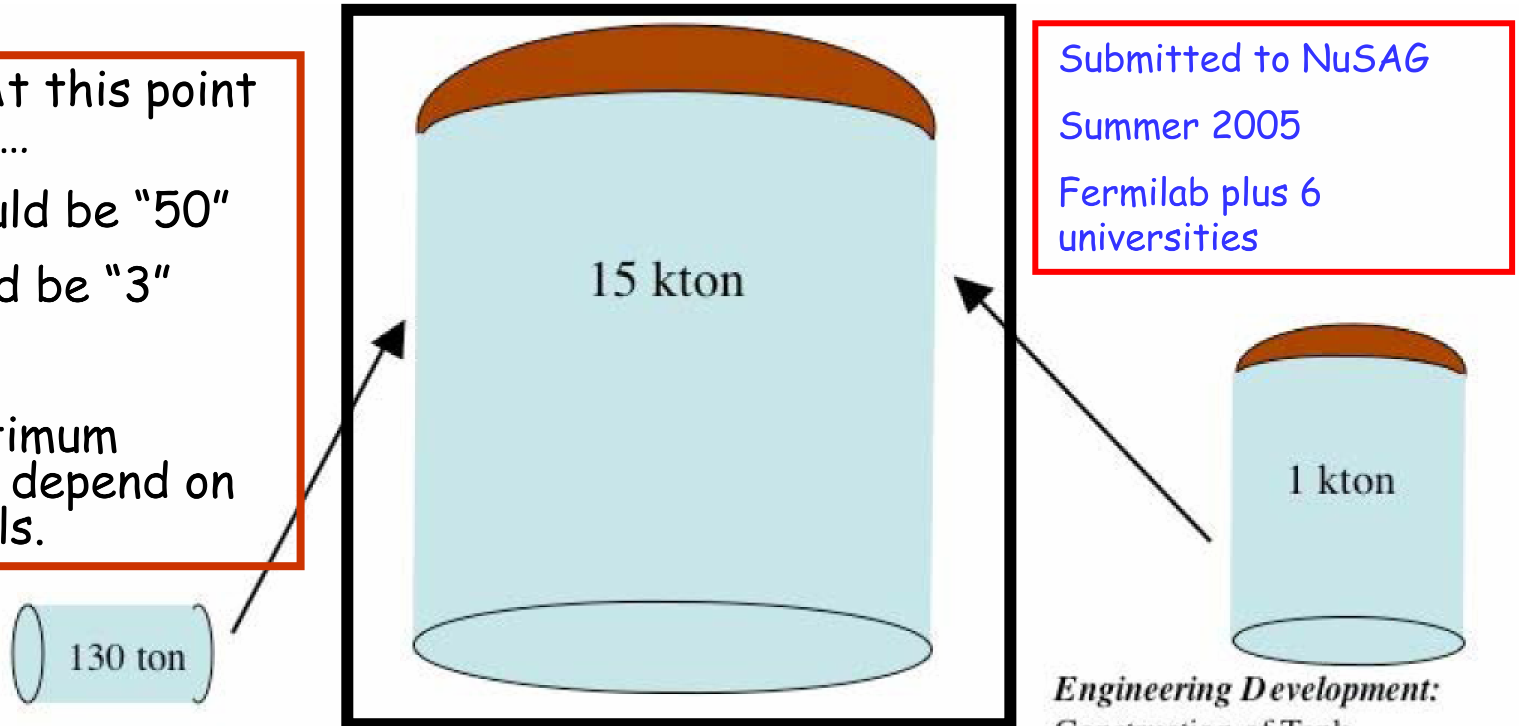
etc

The optimum choices depend on the goals.

Submitted to NuSAG

Summer 2005

Fermilab plus 6 universities



Physics Development *using* ***existing*** *technology*
Record **complete neutrino interactions**: (ν_e & ν_μ)
Establish **Physics Collaboration**
Develop **Event Identification**,
Develop **Reconstruction**,
Develop **Analysis**,
Establish successful **Technology transfer**

Engineering Development:
Construction of Tank
Argon Purity
Mechanical Integrity of TPC
Readout S/N
Microphonics due to Argon Flow

Technical Setups

Purity Monitor Development | Materials Tests | 5 m Drift Demonstration | Long Wires Tests | Electronics Development

Summary

- LArTPC Detector Designs and Costing
  - Ultimate … Penultimate … on going …
- Reasons for the Penultimate Detector:
  - Physics case(s) for Penultimate and Ultimate Detectors
  - Demonstrate scaling of costs and technology to Ultimate Detector
  - Development of international collaboration and funding sources required for Ultimate Detector
- LArTPC group is in an R&D stage
- NuSAG is getting more interested (in cost, schedule, feasibility …).

Backup Slides

Schedule

- The LArTPC schedule in the NuSAG submission did not include the DOE approval process.
- The work on the schedule for the (Pen)Ultimate detector has not started in any serious way.

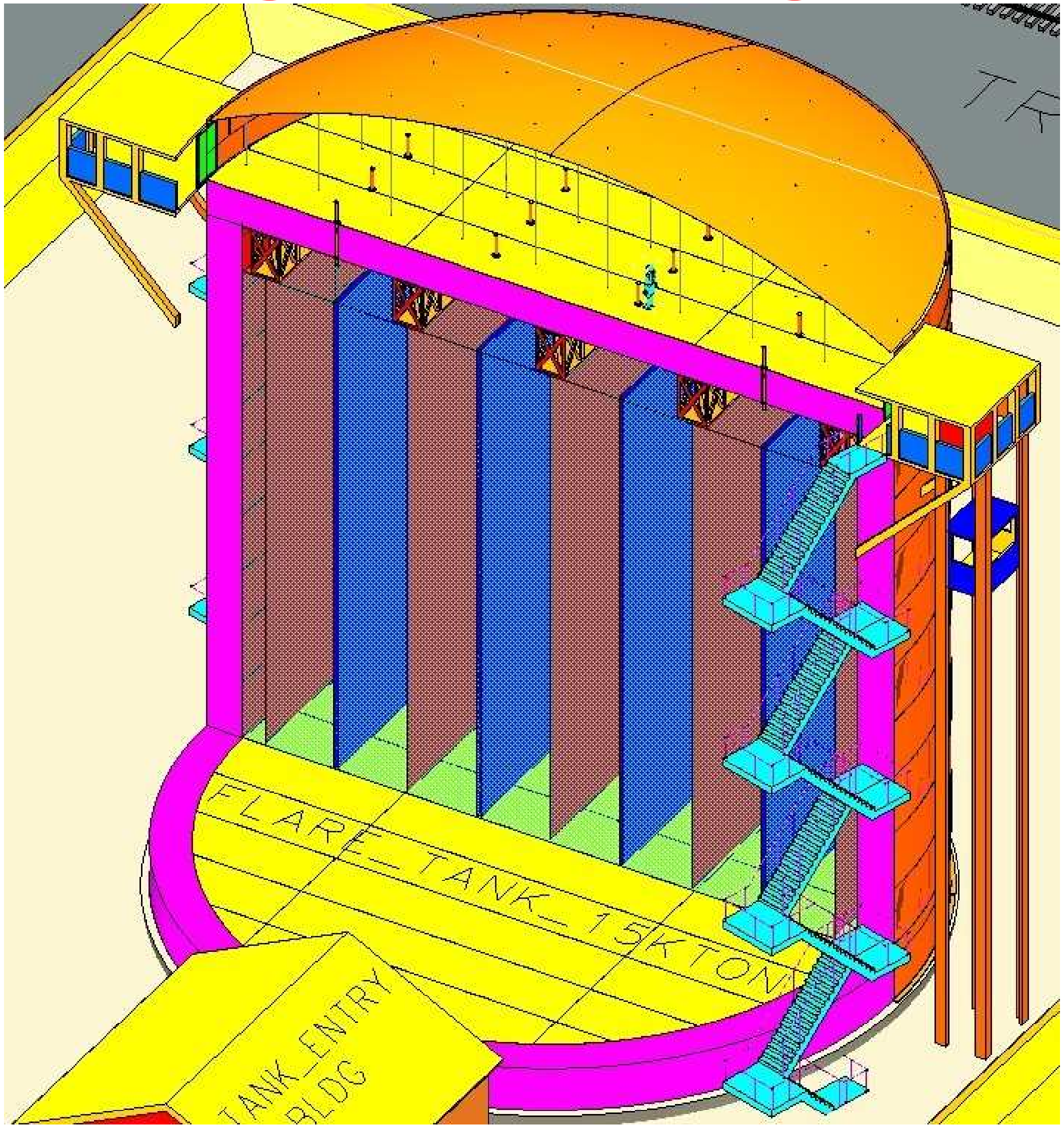
Next cost steps

- Methodology and archeology
  - "Include project management" items so that the Directorate can compare LArTPC costs to other DOE-costed competitors for the funds.
  - "Get ICARUS costs directly from INFN"
    - so we can benefit from their experience
    - and relate "Italian cost accounting" to "DOE cost accounting"
    - so one can better specify what NuSAG meant by "about an order of magnitude" less
- What does "cost" mean? It means:
  - DOE defensible

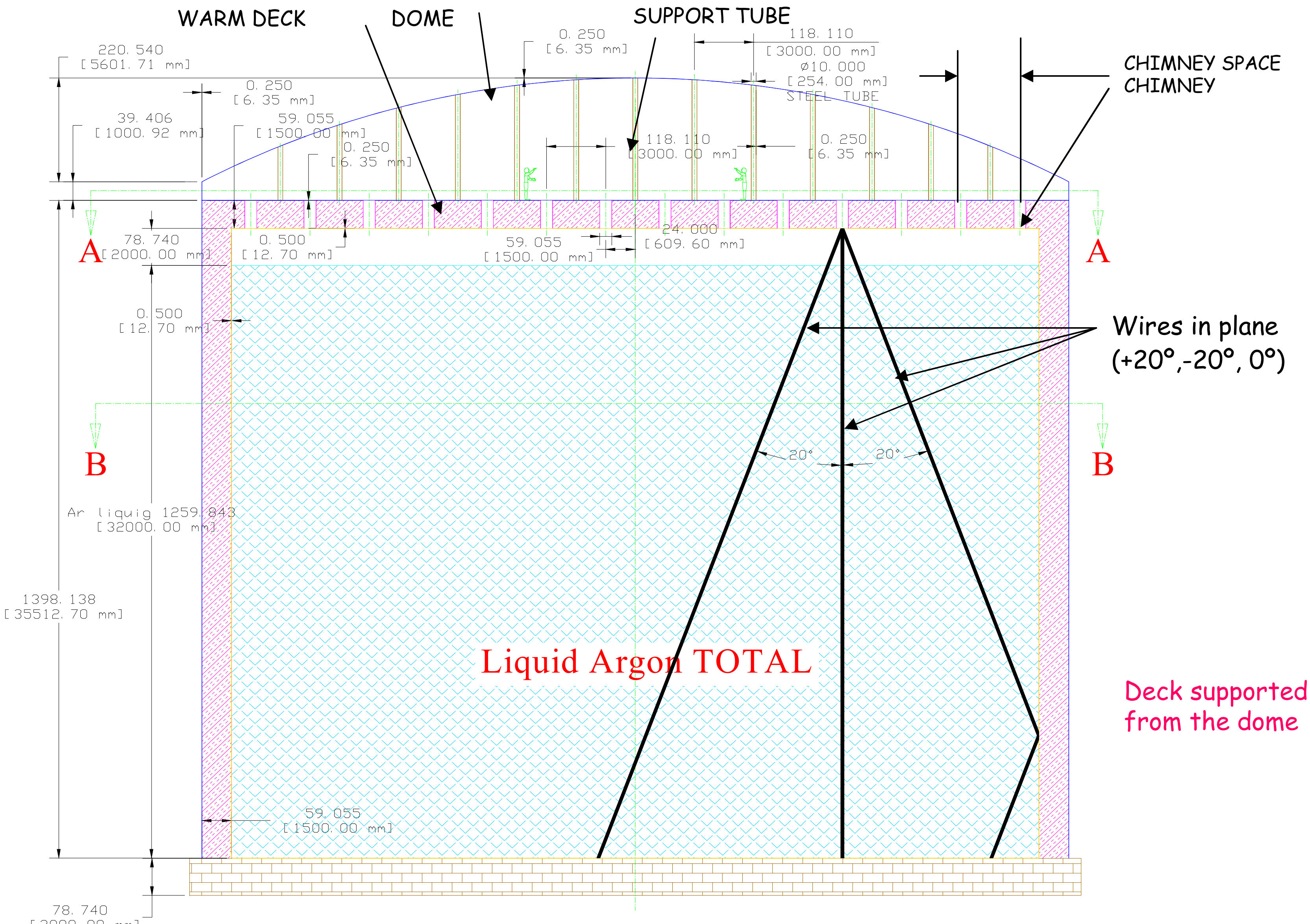
Next cost steps

- Some informative specific design choices
  - 3 kton … three 15 kton … 30 ktons … 50 kton … 100 ktons …
    - what else? …
    - and what experiments drive these choices?

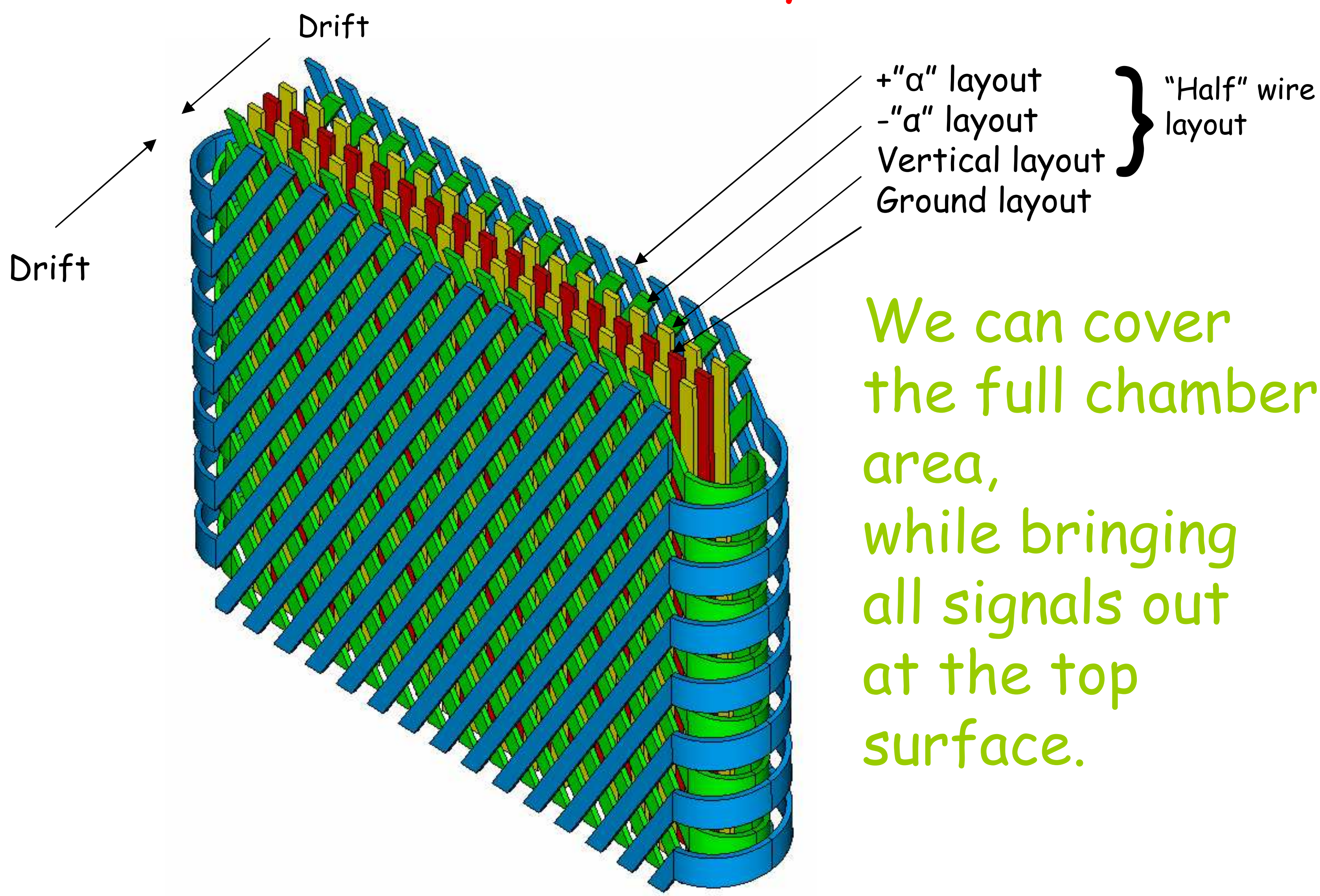
Large Tank Design



LArTPC 50KT (wire plane section)



A Clever Wire Layout



We can cover the full chamber area,
while bringing all signals out at the top surface.

Diameter (= Height) vs. Argon Mass